Analysis of Progress Process of Individual Vehicle in the Congestion Section Using Vehicle Trajectory Data

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ABSTRACT
The purpose of this paper is to perform a study on the progress process of individual vehicles to pass through the recurrent congestion section, which can be achieved through analyzing the individual vehicular data in the microscopic approach. Using the Next Generation Simulation (NGSIM) data for the microscopic analysis, this study analyzed the traffic characteristics at the weaving section. The study was undertaken by two approaches: macroscopic and microscopic analyses. Firstly, this research produced the aggregated traffic data such as flows, speeds, densities in 30 seconds by lane for the macroscopic analysis. Secondly, the individual vehicular data by lane were used and analyzed for the microscopic analysis. The study contains to analyze the lane characteristics through flows, speeds, densities variations and to investigate the trajectories of individual vehicles of mainline flow at the congested traffic state by Time-Space, Speed-Spacing and Speed-Headway diagrams. The basic theory to be used in developing new microscopic traffic flow model is proposed which can describe the progress process of individual vehicles in the congested flow observed in the real traffic situation.

1. INTRODUCTION

Recurrent congestion sections on a freeway are generally classified into ramp merge, ramp diverge, weaving section, upgrade section, and lane drops. Compared with basic freeway sections, there are more various and complex traffic behaviors as drivers must finish lane-changing within a limited length of sections, Because two or more traffic streams traveling in the same general direction cross and change lanes along a significant length of freeway, the probability of congestion at the lower flow state is subject to be high and this causes the LOS (level of service) of whole freeway to be deteriorated.

Among these sections, a weaving section is representative freeway bottlenecks where a mainline traffic is conflict with ramp traffic, and traffic in this section is subject to turbulence in excess of that normally present on basic freeway sections. Result by turbulence has an influence on breakdown that is associated with a phase transition from free flow to congested flow at the bottleneck. Thus, these sections require a concrete analysis and a fully understanding on the congested flow.

Over the decades, several studies have attempted to describe the congested flow in the macroscopic views to interpret the congestion pattern with traffic variables: flows, speeds, and densities. However, no study on the congested flow has been performed with a view of microscopic level based on individual vehicular data. Most researches, so far, have dealt with the congested flow with respect to the phase transition of flow using the aggregated interval data.

Therefore, it is aimed for this paper to analyze the congested flow characteristics with a view of time, space, spacing and headway based upon the each observation of individual vehicles at freeway congestion sections.

2. LITERATURE REVIEW

A. Theory of Newell

Newell (1963) explains the instability of congested flow with car-following theory which describes dense highway traffic. Newell insists that different acceleration and deceleration make different car-following form, and also interpreted car-following model which is affected by acceleration and deceleration, with speed-spacing diagram. In Figure 1 he interpreted that it is shown different spacing in same speed by acceleration and deceleration, and the spacing in acceleration is bigger than the spacing in deceleration and it shows the formation process of hysteresis ring in anti-clockwise.

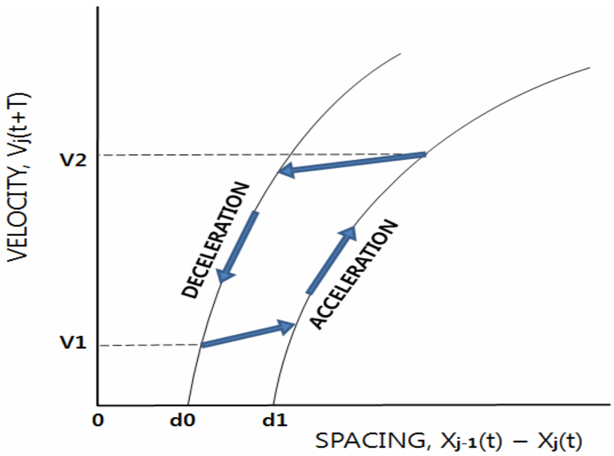


Figure 1. Acceleration and deceleration pattern on speed-spacing diagram

B. Traffic Breakdown

The breakdown phenomenon has a probabilistic nature. At the same freeway bottleneck the speed breakdown in an initial free flow is observed at very different flow rates in different realizations (days) (Elefteriadou et al., 1995; Persaud et al., 1998; Lorenz and Elefteriadou, 2001). The breakdown phenomenon is an abrupt drop in average vehicle speed in the vicinity of a freeway bottleneck. In three-phase traffic theory, the well-known breakdown phenomenon at the bottleneck is associated with a phase transition from free flow to synchronized flow at the bottleneck. The onset of congestion in an initial free flow is accompanied by a sharp decrease in average vehicle speed in the free flow to a considerably lower speed in congested traffic. This speed breakdown occurs mostly at freeway bottlenecks and is called the breakdown phenomenon (Kerner, 2004).

3. DATA GATHRING

This study made use of data sets involved digitizing vehicle positions from time-lapse video recording performed by U.S. FHWA in order to analyze microscopic vehicular traffic flow and transforms them in accordance with the purpose of research with four sites of weaving sections. Data for Los Angeles at U.S. Highway 101 was selected to analyze for this research since traffic congestion occurred at these sites. Table 1 shows data description available for weaving section, and Figure 4 also shows the layouts of sites described in this study.

Table 1. Data description

Content	Video Record (NGSIM)
Agency Distributed	Federal Highway Administration (2004, 2005)
Freeway Geometry	Weaving section of 4 sites Signal intersection of 1 site
Units	Frame: 1/10 of a Sec. or 1/15 of a Sec. Length : feet, Speed : feet/sec Acceleration : feet/sec^2
Data Collecting Period	45 minutes or 60 minutes

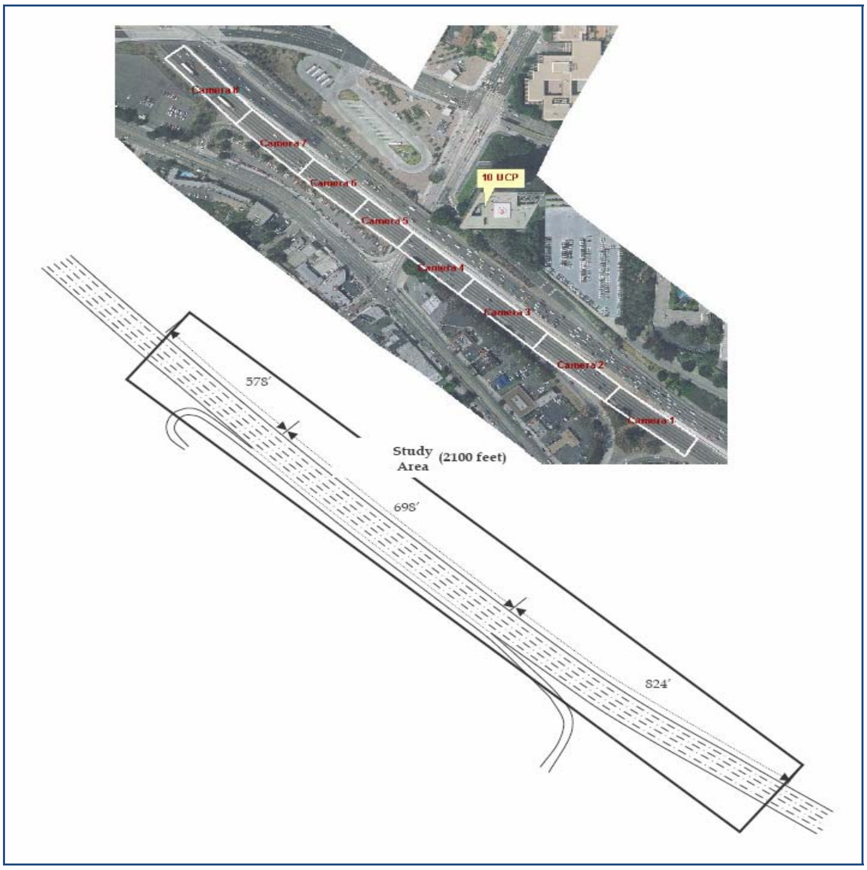


Figure 4. Layout of a weaving section on the Los Angeles at U.S. Highway 101

Table 2 shows the format of the data file created as a result of the digitizing process. The distance of each vehicle from the beginning point of each section is shown in Local Y field for NGSIM data, and the lateral position is shown in Local X field for NGSIM data. Each speed is given in vehicle velocity field. Records with a zero speed represent vehicles which had only been digitized once at this point in the file. And therefore, a speed history could not have developed a speed history. As indicated, the file is organized by frame number, with vehicles ordered sequentially from the downstream to upstream end. Lane position of vehicle is shown in Lane Identification field. Lane 1 is farthest left lane; lane 5 is farthest right lane. Lane 6 is the auxiliary lane between Ventura Boulevard on-ramp and the Cahuenga Boulevard off-ramp. Lane 7 is the on-ramp at Ventura Boulevard, and Lane 8 is the off-ramp at Cahuenga Boulevard. NGSIM data were using 8 video cameras, named camera 1 through camera 8, with camera 1 recording the southernmost, and camera 8 recording the northernmost section of the study area. Digital video images were collected over an approximate nine-hour period from 7:00 a.m. to 12:00 p.m. and from 3:00 p.m. to 7:00 p.m. on June 15, 2005. Complete vehicle trajectories were transcribed at a resolution of 10 frames per second.

Table 2. Sample record format of NGSIM data file

Vehicle ID	Frame ID	Total Frames	Global Time	Local X	Local Y	Global X	Global Y	Vehicle Length
2	21	437	1.12E+12	11.159	258.85	6.45E+06	1.87E+06	14.5
2	22	437	1.12E+12	11.475	274.11	6.45E+06	1.87E+06	14.5
2	23	437	1.12E+12	11.837	289.33	6.45E+06	1.87E+06	14.5
2	24	437	1.12E+12	10.68	305.64	6.45E+06	1.87E+06	14.5
2	25	437	1.12E+12	10.777	323.16	6.45E+06	1.87E+06	14.5
2	26	437	1.12E+12	10.882	340.68	6.45E+06	1.87E+06	14.5

Vehicle Width	Vehicle Class	Vehicle Velocity	Vehicle Acceleration	Lane Identification	Preceding Vehicle	Following Vehicle	Space Headway	Time Headway
4.9	2	48.01	4.3	1	0	10	0	0
4.9	2	49.87	-0.89	1	0	10	0	0
4.9	2	50.64	6.8	1	0	10	0	0
4.9	2	57.64	10.78	1	0	10	0	0
4.9	2	58.27	6.61	1	0	10	0	0
4.9	2	55.1	-2.06	1	0	10	0	0

4. DATA ANALYSIS

In the case of the U.S. Highway 101, the traffic in only lane 1 experiences congested flow among five lanes of this site. Therefore, this study will deal with only lane 1 that the congested flow is expected to occur.

A. Traffic Characteristics

This study required some representative stations for each segment to analyze the traffic characteristics of weaving section and five stations were selected in this paper. The 300 ft station was for the upstream of weaving segment, 600 ft station between the upstream of weaving segment and the weaving segment, 900 ft station for the centre of weaving segment, 1200 ft station for the end of weaving segment, 1500 ft station for the downstream of weaving segment. The flows, speeds, and densities were produced at every 30-second interval at each station.

For flow variation pattern in lane 1, the data of all stations showed that the flows repeatedly increased and decreased from 20 second to 700 second and the flows decreased in the order of 1200 ft, 900 ft, 600 ft, and 300 ft stations except 1500 ft station after 60 seconds. However, it seems that it was also difficult to identify the characteristics of congested flow with only variation of flows.

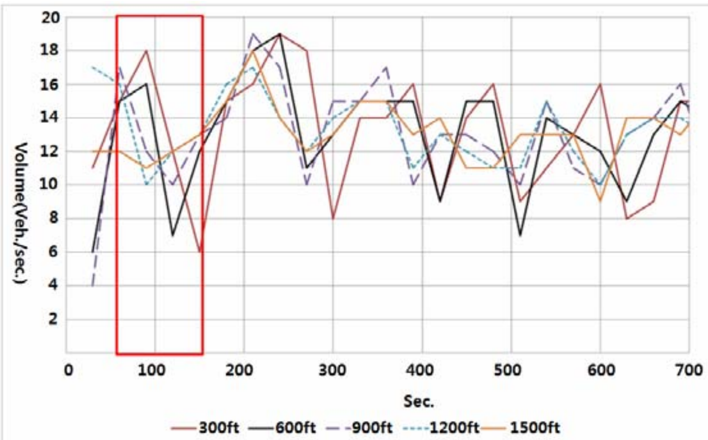


Figure 5. Flow variation pattern at each station at U.S. Highway 101

For speed variation pattern in lane 1, the data of other 4 stations except 1500 ft station showed that speeds repeatedly decreased and increased from 20 second to 700 second and speeds dropped in the order of 1200 ft, 900 ft, 600 ft, and 300 ft stations. The speeds at 600 ft station were the lowest between 0 and 200 seconds. It seems that the breakdown repeatedly occurred between 0 and 700

seconds and the first congested flow happened significantly between 900 ft and 1200 ft stations.

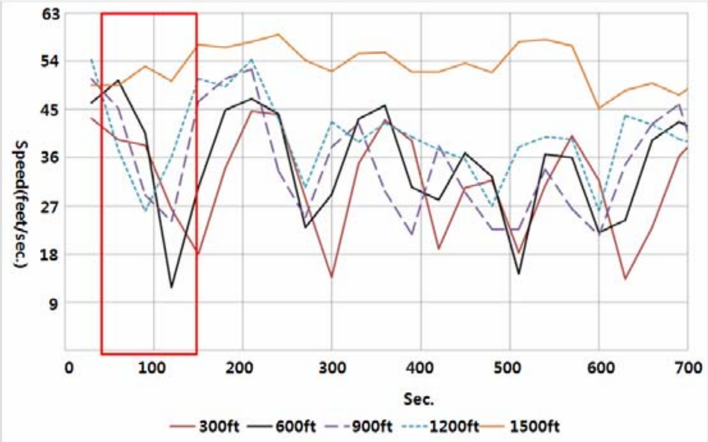


Figure 6. Speed variation pattern at each station at weaving section

It was shown that the densities in lane 1 repeatedly increased and decreased at other 4 stations except 1500 ft station from 20 second to 700 second and the densities increased in the order of 1200 ft, 300 ft, 900 ft, and 600 ft stations. It seems that the first congested flow occurred between 50 and 150 seconds and the traffic at 900 ft and 1200 ft stations.

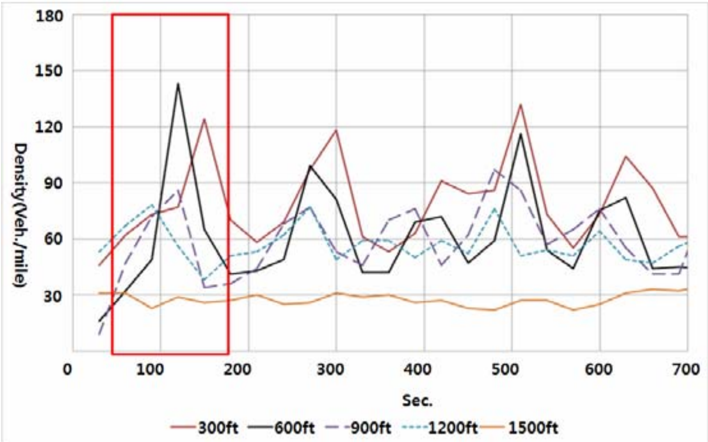


Figure 7. Density variation pattern at each station at weaving section

B. Time-Space Diagram

In this paper, we investigate each lane's time-space diagram to macroscopically confirm mainline lanes of traffic condition in view of time-space. As a result, it is found that the congested flow is created in the first lane of mainline lanes. In view of time, initially the congested flow was created in early 70s seconds and, it was repetitively created until 900 seconds. It is estimated that the congested flow between 70 seconds and 800 seconds seems to start within the weaving section, congested flow after 800 seconds started from the downstream of the weaving section and influence in the weaving section. The congested flow which occurs initially in time-space diagram of first lane in mainline lanes show changes of slope in between 1000~1500 feet at 70 seconds and shock wave was formed to direct to upstream. After 100 seconds, it is found that traffic congestion is aggravated according to the time of 0 slope of individual vehicle increased as it goes to upstream. In other words, It is analyzed that traffic breakdown is occurred between 1000 and 1500 feet, and between 450 seconds and 460 seconds. Although the result of the analyzed time-space diagram shows more accuracy traffic condition than analyzed traffic characteristics, it is hard to analyze a specific characteristic of individual vehicle.

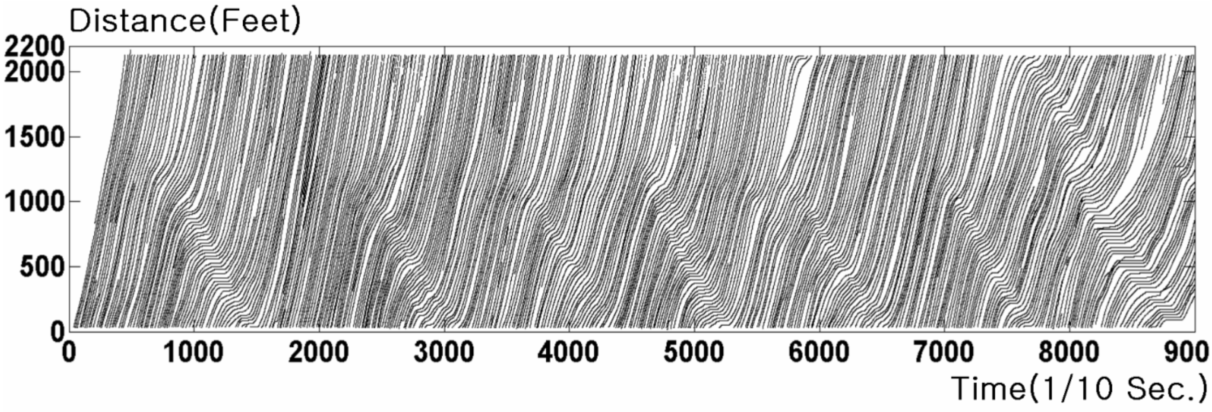


Figure 8. Time-space diagram

C. Speed-Spacing Diagram

In this paper the congested flow was accounted with the time-space diagram. Although the time-space diagram was accounted with the condition of macroscopic traffic flow, it was hard to analyze the characteristic of microscopic individual vehicle. Therefore I tried to confirm the pattern which occurs when an individual vehicle go through congested segment by analyzing individual vehicle with speed, headway and spacing in the condition of stability flow and congested flow.

Figure 9 illustrates speed-headway diagram by differences of speed between preceding and following vehicle in stability flow. Individual vehicles speed-headway diagram at stability flow between 0~800 seconds shows similar pattern mostly.

At first, speed-spacing diagram in stability flow shows that speed was changed between 55 and 68 feet and between 45 and 70 feet and both preceding and following vehicles seem like the data of acceleration and deceleration is mixed. It is seem that the time of acceleration and deceleration in stability flow occurred repeatedly in very short time and it is estimated that any specific pattern wouldn't be occurred.

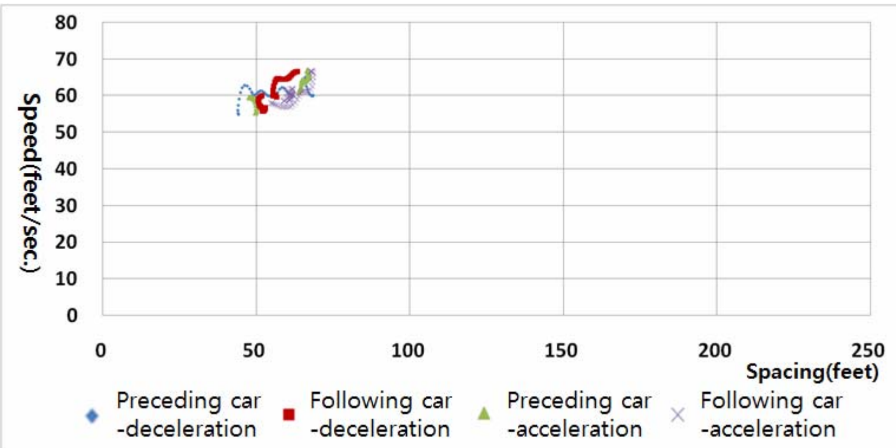


Figure 9. Speed-spacing diagram on stability state

This paper shows that 4 types pattern of the process which the stability flow become congested flow and recover to the stability flow again with individual vehicle speed-spacing diagram and the patterns of acceleration and deceleration.

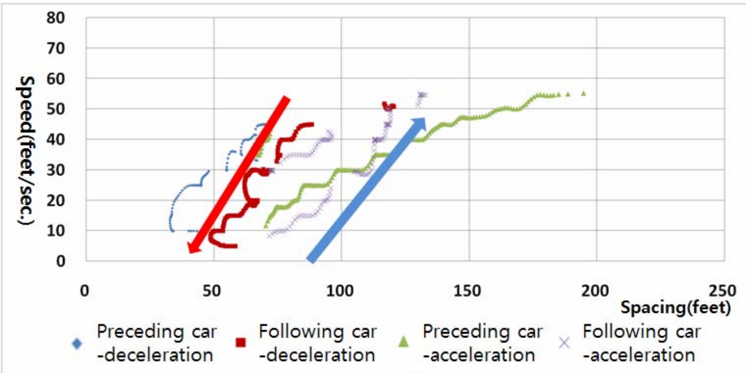
Speed-spacing diagram in type 1, it shows that headway is longer when preceding and

following vehicle have same speed and at acceleration than deceleration, and hysteresis ring which is formed through that the stability flow recover it's status again after congested flow, to anti-clockwise rotation and deceleration of headway is more sensitive than acceleration.

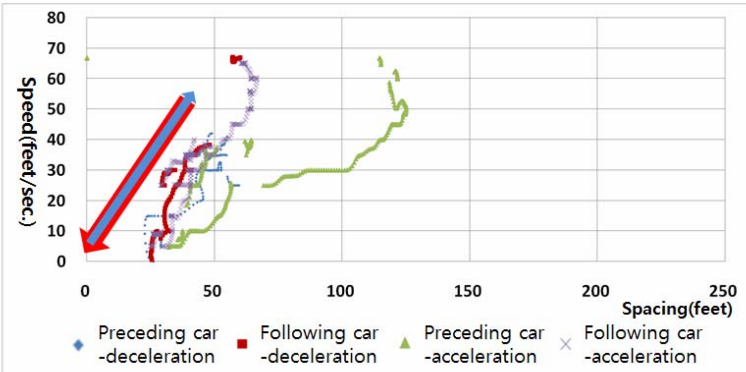
The speed-spacing diagram in type 2 shows similar headway of acceleration and deceleration in same speed such as acceleration and deceleration mixed on the same line. It is analyzed that acceleration and deceleration patterns are changed frequently while it happened in a short time in short spacing because the pattern such as type 2 occurred frequently when individual vehicles drives in 50 feet spacing. Then according to the analysis about drivers' characteristic in type 2, they would react sensitively to acceleration and deceleration of preceding vehicle and the reaction will be similar.

According to speed-spacing diagram in type 3, in opposition from type 1, pacing in deceleration is larger than spacing in acceleration at the same speed and the driver react quickly to deceleration of preceding vehicle than acceleration. It is found that in type 3 the spacing with preceding vehicle is kept in the distance (more than 100 feet) in deceleration.

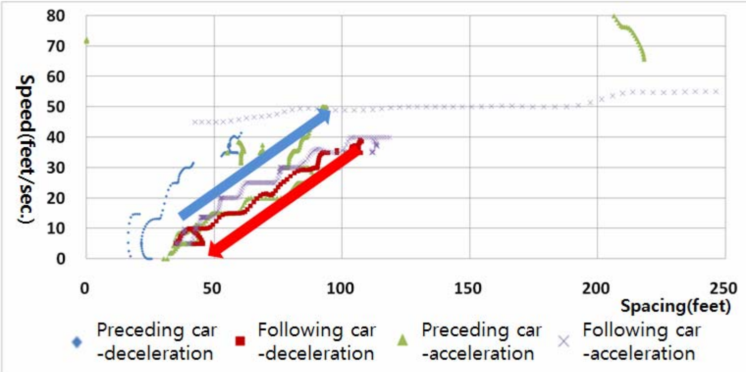
At last speed-spacing diagram in type 4 also show that spacing increased as long as speed decreased, which wasn't appeared at type 1, 2 and 3. It is estimated that this is occurred when speed of preceding vehicle is faster than following vehicle and acceleration and deceleration speed was slower than the following vehicle. And also the deceleration pattern of type 3 is mainly occurred within 50 feet like type 2.



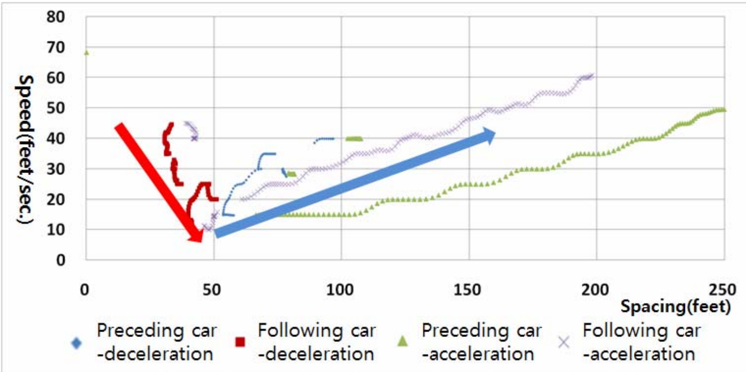
a. Type 1



b. Type 2



c. Type 3



d. Type 4

Figure 10. Speed-spacing diagram on instability state

Characteristic of the individual vehicles, which processed from stability flow returns to stability through congestion flow, are divided in 4 types like Figure 11 and has a driver's characteristic and transfer process.

In the process which the stability flow returns to stability through congestion flow, when stability flow is transferred to congestion flow, the speed and spacing is reduced but the speed and spacing increased. And driver decreased spacing when it approached to speed in the stability flow then kept the spacing with preceding vehicle when it reached to driver's desired spacing. In other words, the process, which stability flow returns to stability through congestion flow, illustrates in Figure 11 in order of 1-2-3 and the spacing is broaden and the speed was increased between the congestion flow and stability flow then when it reached the desired spacing it decreased the spacing and drives based on desired spacing.

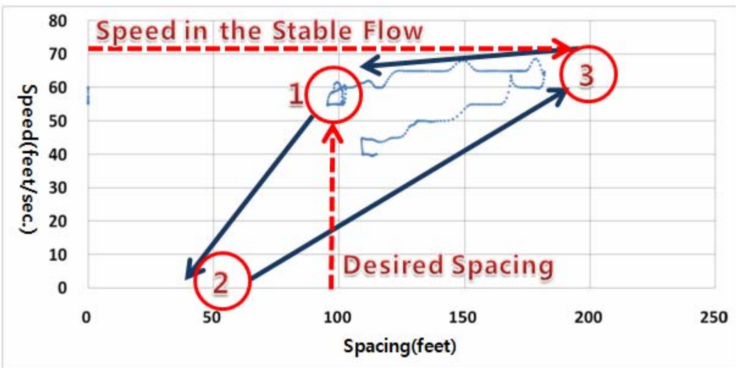


Figure 11. Variation pattern of traffic on speed-spacing diagram

C. Speed-headway Diagram

The diagram of the speed-headway was analyzed based on 4 patterns of speed-spacing diagram. At the first, the speed-headway diagram shows that the acceleration and deceleration was occurred through 1 second of the head way during 55~68 feet/second and both preceding and following vehicles seem like the data of acceleration and deceleration is mixed. Figure 12 illustrates that the driver's desired headway at 60feet/s is 1 second.

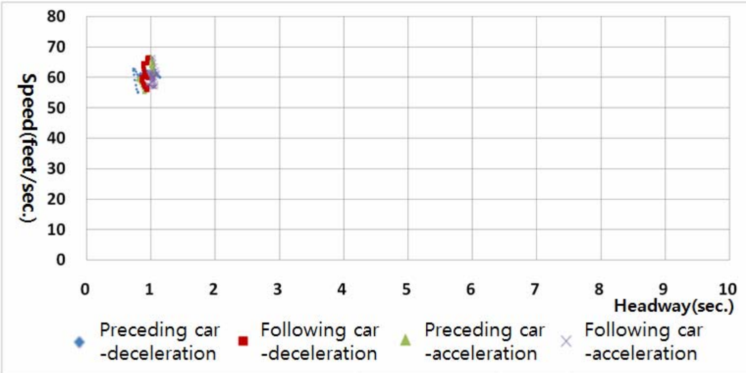


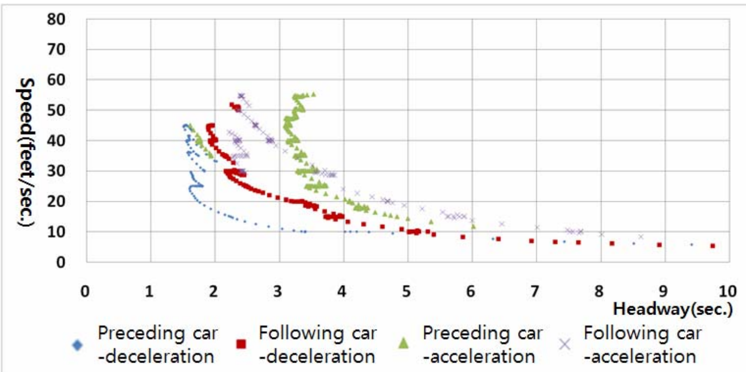
Figure 12. Speed-headway diagram on stability state

The speed-headway diagram in Type 1 shows that both preceding vehicle and following vehicle at same speed increased headway in acceleration rather than in deceleration and it is estimated that because of car-following relationship of preceding vehicle, oscillation pattern from side to side is shown.

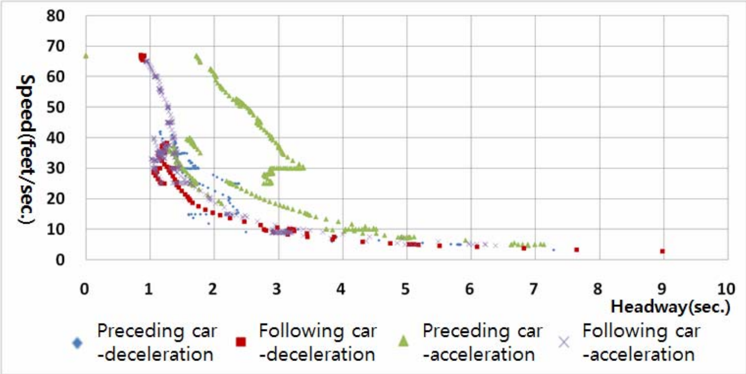
The speed-headway diagram in type 2 shows that the headway of acceleration and deceleration were similar such as speed-spacing diagram. The pattern like type 2 occurs frequently when headway is below 2 seconds.

The type 3 show opposite result to the type 1 like speed-spacing diagram, and it is more sensitive to acceleration rather than deceleration at same speed and when the spacing is longer. And like type 1 in the acceleration it shows vibration pattern at 3 second and the speed increased.

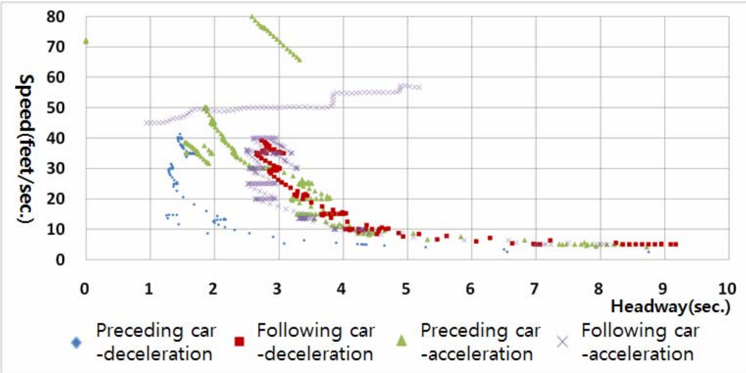
At last, the speed-headway diagram in type 4 shows that the data indicated the same pattern as type 1, 2 and 3 in deceleration in opposition to spacing and it shows vibration pattern between 3 and 3.5 second and the speed is accelerated like a acceleration pattern as type 1 and 3.



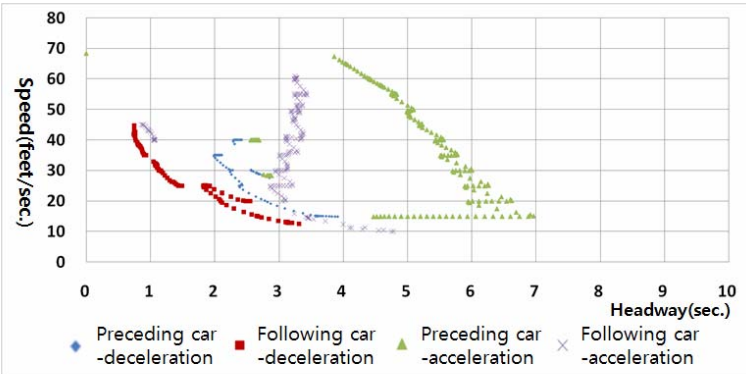
a. Type 1



b. Type 2



c. Type 3



d. Type 4

Figure 13. Speed-headway diagram on instability state

It is analyzed in speed-headway diagram that 4 phase of transfer process appeared while stability flow returns to stability through congestion flow.

The first phase in Figure 14 illustrates that stable flow(1) proceed to congested flow(2) and at the same time the headway dramatically increased and slowed and the second phase shows that the headway is steadily decreased by speeding when the congested flow(2) proceed to stability flow when headway appeared in the discharge flow(3).

The third phase shows that the process of stability flow when headway appeared in the discharge flow(3) proceed to condition recovered speed in the stable flow(4). And it is a phrase that shows the vibration pattern to reach to the speed in the stable flow. It is also analyzed as headway which is reduced until driver want before it reach the speed in the stable flow(4).

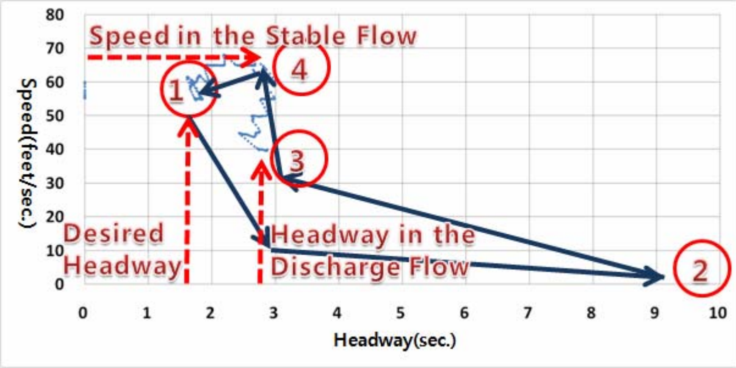


Figure 14. Variation pattern of traffic on speed-headway diagram

5. CONCLUSIONS

This research use data of individual vehicle to explain to transition process between stability flow and congestion flow in view of microscopic, so it help to clearly understand the process and it provide basic theory for efficient traffic management of high way by traffic condition.

We use NGSIM of real highway to analyze every 30-second interval of volume, speed, density, and time-space diagram by macroscopic view and by microscopic view, we performed analysis by making diagram of speed-headway and speed-spacing. As a result there are 4 different types according to the driver's characteristic during transfer process of stable flow and congested flow and the speed in stable flow and driver's desired spacing influenced on transfer pattern. When congested flow is recovered to stable flow, in speed-headway diagram, it is found that the speed in stable flow and driver's desired headway and driver's desired headway in stability flow influences on transfer pattern. The different driver's desired headway in stability flow and congested flow.

Result of the research shows that it will be able to apply as a fundamental theory for traffic management technique at future intelligent high. It will be helpful to grasps the traffic quality of the intelligent vehicle which the system is applied, and to be able to applied to judge the effective scale to analysis the application effect of intelligent vehicle and highway. In the future microscopic analyses is needed for congested flow in different road and traffic condition and the theory should be materialized through quantitative analysis and develop to be a traffic model.

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